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THE DUST HAZARD IN THE ABRASIVE INDUSTRY*

W. IRVING CLARK, M.D., AND EDWARD B. SIMMONS, M.D.

Norton Company, Worcester, Mass.

INTRODUCTION

DURING the past ten years the use of artificial abrasives in industry has enormously increased. The preference in almost all metal trades for these abrasives, in the form either of grain or of grinding wheels, has made a study of the hazard of abrasive dust inhalation of great importance.

The natural sandstone wheel which is known to be productive of silicosis is now used only in the manufacture of cutlery and axes, and even in these industries it is being slowly replaced by the artificial abrasive wheel. Some idea of the amount of the artificial abrasives required by industry is shown by the fact that the United States alone in an average year produces 60,000,000 pounds of artificial grinding wheels.

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The two artificial abrasives in most common use are aluminium oxide and silicon carbide. In each case the crystal is hard, tough, of a cutting power near that of diamond, and, when divided, wedge-shaped in form. In the crushing and sizing of these crystals into the different sized grains, as well as in the manufacture of grinding wheels, large quantities of dust are produced. The workers are protected from the worst of this dust by dust collection suction systems which remove the greater part of the dust occurring at or about the machines. There is, however, a considerable amount floating in the air of the dusty departments; this paper is a study of the effect of continuous inhalation of this dust on the health of workers.

LITERATURE

A search of the literature fails to reveal any clinical report on the effect of the inhalation of the dust of arti-

ficial abrasives. In 1919, Winslow, Greenburg, and Greenberg (1) made a study of the dust hazard in the abrasive industry by dust analysis. They made dust counts and dust weights in two abrasive factories and as a result they reached the conclusion that, because of the extremely high dust count and the physical characteristics of the dust, a high frequency of pulmonary fibrosis and tuberculosis should be found in the industry. They say:

> Statistical analyses and special intensive and experimental studies alike have shown that the most hazardous of the dusty trades are those in which the workers are exposed to the inhalation of small, hard, sharp, nonabsorptive particles. The continued inhalation of metallic and silicious particles first of all initiates a fibrosis, which is the primary reaction to their deposition in the lung tissues, and then leads, in a majority of cases, to the development of pulmonary tuberculosis in the injured organ.
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> Among the various types of workers liable to industrial tuberculosis, grinders and other users of abrasive materials are recognized as being among the worst sufferers; and it has generally been assumed that the mineral particles thrown into the air from the abrasive material itself are as important factors as the metallic dust from the object subjected to the grinding or polishing treatment. Yet, curiously enough, so far as we are aware, no one has hitherto called attention to the peculiar hazard which menaces the workers engaged in the manufacture of the abrasive materials themselves.
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> The inorganic fraction of the dust in the air of the abrasive factories studied by the writers includes at least four different materials—coke, crude aluminum hydroxide, a fused aluminum compound (aloxite or alundum) and carborundum.[1] The exact harmfulness of coke dust is not yet fully determined and the crude aluminum hydroxide is made up of softer and more rounded particles than the carborundum or the fused aluminum compounds. The last two types of material may for practical purposes be considered to possess the same physical properties. Both derive their chief value from their hardness, which is between 9 and 10, carborundum being said to approach very closely in hardness to the diamond. In addition to this property, these materials also possess the property of fracturing in very irregular particles. We have examined many specimens of these dusts and found them to be exceedingly hard, exceedingly sharp, and made up to the extent of 95 to 100 per cent of inorganic material.
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> We have every reason to expect from analogy with other industries in which workers are exposed to a similar hazard, that dusts of this nature should be exceedingly deleterious to health.

[1] Carborundum is silicon carbide, one of the two abrasives being considered.

Many studies have been made of the effects of the inhalation of silica dust produced by grinding with sandstone wheels or in mining but, with the exception of an investigation made in 1923 by Dr. E. L. Middleton (2), no examination of grinders using wheels made of artificial abrasive has been recorded. Middleton examined 1,153 grinders in various factories in England and found fifty-three cases of pulmonary tuberculosis, distributed as follows:

Wet sandstone hand grinders	35	= 7.07%
Wet sandstone machine grinders	1	
Dry sandstone grinders	1	
Cutters	3	
Grinders using machine manufactured wheels	1	18 = 2.76%
Glazers	9	
Dressers	3	

Middleton divides fibrosis into three

degrees. In his examination of fifty-eight grinders using machine manufactured wheels, three showed symptoms or had physical signs of first-degree fibrosis. None had symptoms or signs of second-degree or third-degree fibrosis. On the other hand, of 269 wet sandstone grinders, 217 had some form of fibrosis—159, first-degree fibrosis; fifty, second-degree; and eight, third-degree.

From this report and from other reports made by English investigators, it appears that the inhalation of dust from the artificial grinding wheel is not so dangerous as the inhalation of dust from the standstone wheel. There are two reasons why this may be so: (1) An artificial grinding wheel of proper grain and grade will outwear at least fifteen natural sandstones of the same size. This means that, while grinding a certain number of steel parts on a natural sandstone, about fifteen times as much wheel material is worn away as if the same work were done on an artificial grinding wheel. (2) Many investigators believe that the inhalation of silica is the primary cause of fibrosis and that the higher the percentage of free silica, the more rapid the process.

In England men developing fibrosis while working with material having a silica content of 80 per cent. are considered to have silicosis, and are entitled to compensation.[2]

Present Study

This study is clinical in character and represents fourteen years' experience in the largest single abrasive and grinding wheel factory in the world.[3] The average number of employees during the period has been 2,100, but only about one-fifth of this number have been exposed to the inhalation of large quantities of dust.

In the manufacture of abrasives and grinding wheels there are four departments in which the processes are very dusty. These are the abrasive department where the lumps of abrasives are crushed into grain and sized; the shaving department where the dry wheels, still in clay form, are shaped on a special type of potter's wheel; the truing department in which the now vitrified wheels are cut to exact size on specially constructed lathes; and the clay department where the clays which make up the bond in the wheels are weighed and mixed. The dustiest of these departments is the last. In all departments where abrasive dust occurs, very complete dust removal systems have been in operation for years, and at present the amount of dust collected by this system daily is 12,000 pounds.

All applicants for employment receive a complete physical examination before being hired, and employees working in dusty departments are reexamined as frequently as appears necessary. Those who have been exposed to dust inhalation for ten years are examined annually. All employees are under medical supervision through the factory health department; they are studied at their work and every effort has been made to reduce the dust hazard. The majority of those employed in the dusty depart-

[2] Hayhurst, E. R.: Discussion of Dr. Britton's paper on "Silicosis." This Jour., 1924, *6*, 222.

[3] Norton Company, Worcester, Mass.

ments are of Swedish descent; the next largest group consists of Italians.

A group of seventy-nine men who have been employed ten or more years in dusty departments were examined, and X-ray pictures of their chests were taken. The examinations were made by a member of the factory medical staff and by one of the authors of this paper, and in several cases they were checked by the other author. The X-ray pictures were taken at Memorial Hospital, Worcester, Mass., and were read by Dr. D. C. Jarvis[4] of Barre, Vt., who has spent many years taking and studying X-rays of silicotic chests. We have also analyzed the causes of all deaths reported since 1892 by the Norton Mutual Benefit Association which insures about 40 per cent. of our employees.

Histories Given by the Men

Bronchitis (at some time)	5
Colds (coryza) (occasionally)	54
Cough (occasionally)	5
Expectoration	5
Hemoptysis (in past)	1[5]
Dyspnea	4

Hospital Records

Bronchitis

Number of Attacks	Number of Men
None	52
1	8
2	9
3	5
4	1
5	2
6	1
8	1

Coryza

None	28
1	19
2	7
3	6
4	3
5	5
6	5
8	2
9	1
11	1
13	1
16	1

Influenza

None	49
1	20
2	7
3	2
5	1

Tonsillitis

None	60
1	8
2	7
3	2
4	2

Laryngitis

None	71
1	5
2	3

Pharyngitis

None	55
1	14
2	3
3	4
4	1
5	1
6	1

Grip

None	60
1	14
2	3
3	2

Pleurisy

None	73
1	6

[4] Consultant to Department of Industrial Hygiene, United States Public Health Service; Medical Adviser, Granite Cutters' International Association of America; and Consultant, United States Veterans Bureau.

[5] Pulmonary tuberculosis in 1912; complete recovery.

Pneumonia

None	75
1	4

Physical Examinations

Marital State

	Number
Married	68
Single	6
Widowed	5

Age

	Years
Maximum	68
Minimum	31
Average	32½

Service

	Years
Maximum	38
Minimum	11
Average	17⅓

Weight

	Pounds
Maximum	250
Minimum	110
Average	154¼

General

	Number
Well developed and nourished	60
Fairly developed	14
Poorly developed	5
Thin	9
Obese	5
Flat chested	2
Barrel chested	1
Kyphotic	1
Chicken breasted	1

Respiration (Inspection)

Normal	74
Retraction	1
Limited expansion	4

Percussion

Normal resonance	75
Dulness at right apex	3
Slight dulness under right scapula	1

Breath Sounds

Normal	71
Distant	1
Increased at right apex	7

Voice Sounds

Normal	68
Increased at right apex	8
Distant	2
Increased at right base	1

Râles

None present	76
Few subcrepitant at right apex	1
Small patch subcrepitant under right scapula	1
Coarse mucous	1

Heart

Normal	72
Sounds distant	2
Chronic endocarditis	1
Systolic murmur at apex	2
Roughening first sound at apex	2

X-Ray Findings

From his examination of the X-ray films of the seventy-nine workers habitually exposed to dust, Dr. Jarvis concluded that only one of the men showed signs of silicosis and this was in the incipient stage. This worker was employed in the clay plant where there is no artificial abrasive dust, but a great deal of clay dust. Analysis of the clay showed that it contained 9 per cent. of pure silica which is introduced in the form of feldspar. This is, therefore, probably a case of true, early silicosis.

The chest pictures of the workers exposed to artificial abrasive dust showed lungs which had, in no case, typical signs of silicosis, though in four cases there was evidence that the lungs were working hard to keep themselves clear of dust; that is, they showed a tendency to lymphatic stasis. Dr. Jarvis felt that, if these

were the lungs of granite workers, they would represent a perfectly safe risk for an indefinite time. It was also his opinion that, with the exception of the man exposed to clay dust, none of our men would develop active symptoms of pneumonokoniosis during their natural lives.

At the Company's plants at Niagara Falls and Chippewa, where the crude artificial abrasive is made and handled, seven employees had been exposed to dust over periods of from five and a half to eighteen years. The average period of exposure was eleven and one-tenth years. Physical examination of three of these men showed nothing abnormal in the lungs. Four were not examined. X-rays of all seven chests were taken and were read by Dr. Jarvis, who reported all negative for pneumonokoniosis. In regard to both groups he stated that "The chest X-ray films show an absence of densities which give evidence of the presence of dust disease. They show rather that the men are running a normal lung life."

Analysis of Causes of Death

Analysis of the causes of all the deaths reported by the Norton Mutual Benefit Association since 1892 gives the following statistics:[6]

Cause	Number of Deaths
Non-lung disease	52
Pneumonia	20
Pulmonary tuberculosis	6
Epidemic influenza	13
Total	91

Six and one-half per cent. of all deaths, therefore, were due to pulmonary tuberculosis. This is a little higher than the percentage of deaths due to pulmonary tuberculosis for the city of Worcester in 1924—namely, 5 per cent. In the latter figure, however, the deaths of babies and of very young children were included, so that the probability is that the death rates from pulmonary tuberculosis at the Norton Company and for adults of the city of Worcester are closely akin.

Incidence of Pulmonary Tuberculosis

In order to check further the incidence of pulmonary tuberculosis at the Norton Company, a review of all the cases occurring among its employees during the past ten years has been made. The statistics are as follows:

DEPARTMENT	NUMBER OF EMPLOYEES	PULMONARY TUBERCULOSIS	
		Number	Per Cent.
Non-dusty	1,868	20	0.010
Dusty	332	11	0.033
Total	2,200	31	0.014

These figures show that the percentage of cases of pulmonary tuberculosis was higher in the dusty than in the non-dusty departments, but as the percentage of employees developing pulmonary tuberculosis at work is 0.014 per cent. of the working force each year, the risk does not appear great.

Nicholson (3) states that "In Great Britain it has also been noticed that workers with carborundum—an intensely hard, combined mineral dust—

[6] In each case the cause of death was verified at Worcester City Hall.

do not suffer unduly from tuberculosis of the lungs."

Conclusions

On the basis of fourteen years' observation and of the data presented in this paper, the following conclusions seem to be justified:

1. In factories which provide proper methods of dust removal, the continuous inhalation of artificial abrasive dust, extending over many years, does not produce the symptoms or present the X-ray findings of pneumonokoniosis.

2. The number of cases of pulmonary tuberculosis occurring in the artificial abrasive industry does not greatly exceed the number normally present in the community.

3. Workers who habitually use grinding wheels will run but slight risk of developing pneumonokoniosis if they use artificial abrasive rather than sandstone wheels for all grinding operations, and if the machines upon which the artificial abrasive wheels are mounted are properly hooded and excessive dust removed by suction fans.

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IMPROVED FORM OF THE DRINKER, THOMSON, FITCHET DUST SAMPLER*

PHILIP DRINKER AND ROBERT M. THOMSON

Department of Ventilation and Illumination,
Harvard School of Public Health, Boston, Mass.

IN the gravimetric determination of dust in air, it is often desirable to use apparatus and methods which permit sampling at high rates of air flow. Otherwise it requires too long a time to collect enough dust to make reliable weighings. Recent reports from South Africa (1) show that the dust concentrations in their mine air have been reduced to an average figure of 1.3 mg. per cubic meter. In such localities, dust collecting apparatus running at 30 liters per minute, a customary rate, requires nearly one hour to collect 2 mg. of dust. Runs of such duration are inconvenient, because so few determinations can be made in a day and checks are practically impossible.

It is evident from the enormous number of determinations made by the South African investigators (1) that it is wasted effort to strive for scrupulous accuracy in routine determinations. Nor does it seem to matter whether samples are obtained by devices such as the konimeter, and the particles counted, or by the sugar-tube filter, and the dust weighed. Either method gives useful indices of the amounts and character of the dust inhaled.

* Received for publication April 30, 1925.

WETTING METHODS

If dusty air is bubbled through water, the efficiency of dust removal is governed largely by the effectiveness of the contact between the dust particles and the water or the wet surfaces of the apparatus. If the bubbles are large, some of the dust particles are carried on through the apparatus; if the bubbles are made very small, the resistance to air flow is necessarily great. Therefore, if bubbling methods are used, a balance must be maintained between these two factors—the size of the bubbles and the resistance to air flow.

Unlike the scrubbing of gases by solvents, the kinetics of the dust particles are of no practical importance. Forces of diffusion, brownian movement, and partial pressure, so important in the wetting of fume particles and gases, have no direct parallel in the wetting of insoluble dust particles. It is necessary to produce violent contact between the particles and the wetting medium, and unless this is done, recovery efficiencies are low.

Theoretically, high recoveries are possible with wetting media such as oils or water to which a colloid has been added (2). Practically, these

media induce additional troubles, such as foaming and emulsification with air, so that their advantage over pure water is doubtful. The wetting of the particles has to be accomplished, therefore, by direct contact between the particles and the wetting medium. Of necessity, this contact must be obtained through mechanical rather than physical or chemical agencies.

cent. efficient, in which dusty air was bubbled violently through water at rates of 250 to 300 liters per minute. Although originally calibrated against high dust concentrations, this apparatus has been found to be satisfactory in both field and laboratory work for determinations of dust in low concentrations—*i.e.*, concentrations requiring 10 or 15 cubic meters of air to give reliable gravimetric determinations.

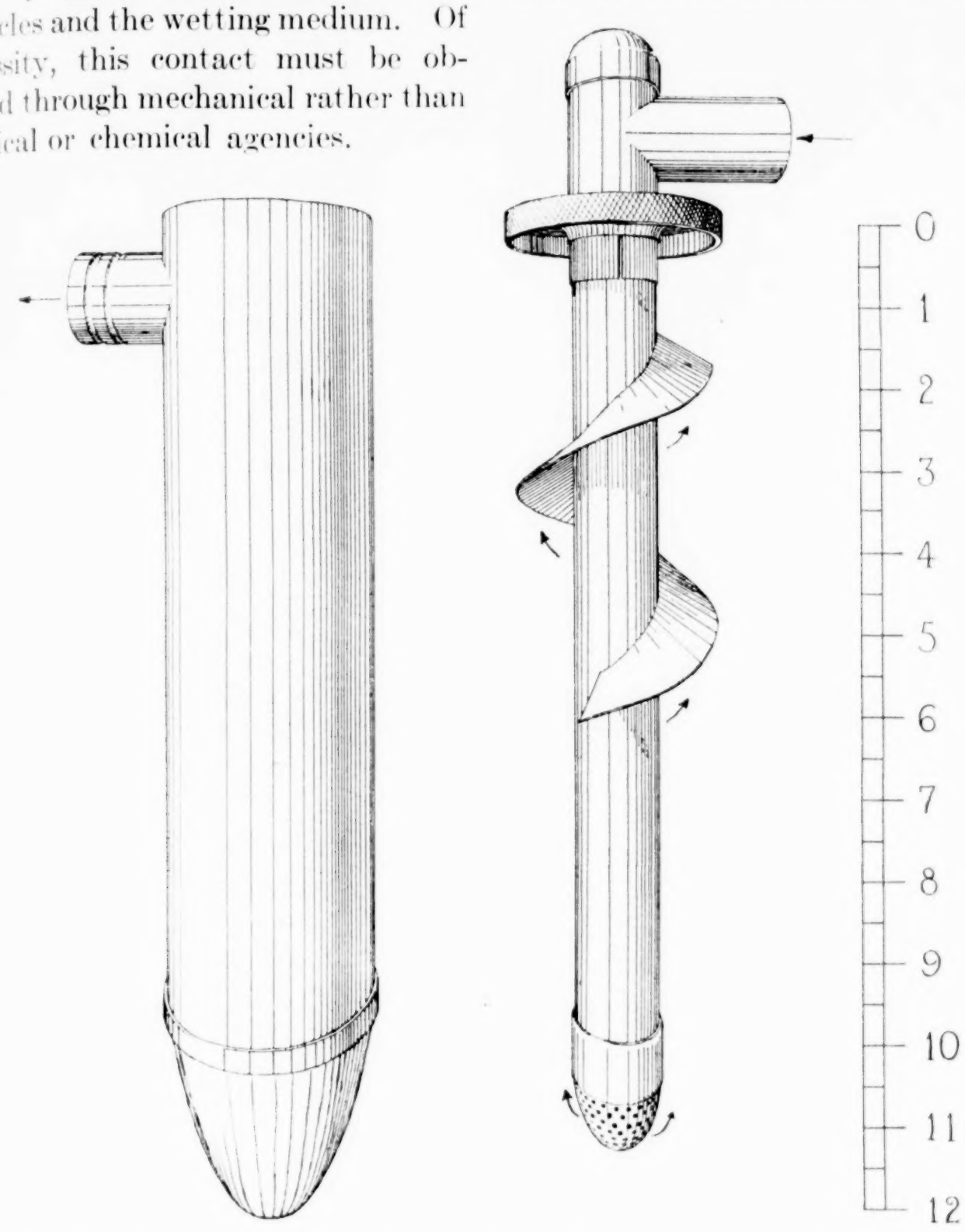

FIG. 1.—Sampling tubes with scale in inches. Dusty air enters side arm, passes down through 1-inch tube, bubbles out through perforated thimble at the bottom, spirals upward, and escapes through the side arm of the larger tube.

THE DRINKER, THOMSON, FITCHET DUST SAMPLER

In 1923, we described (2) a type of dust sampler, approximately 95 per

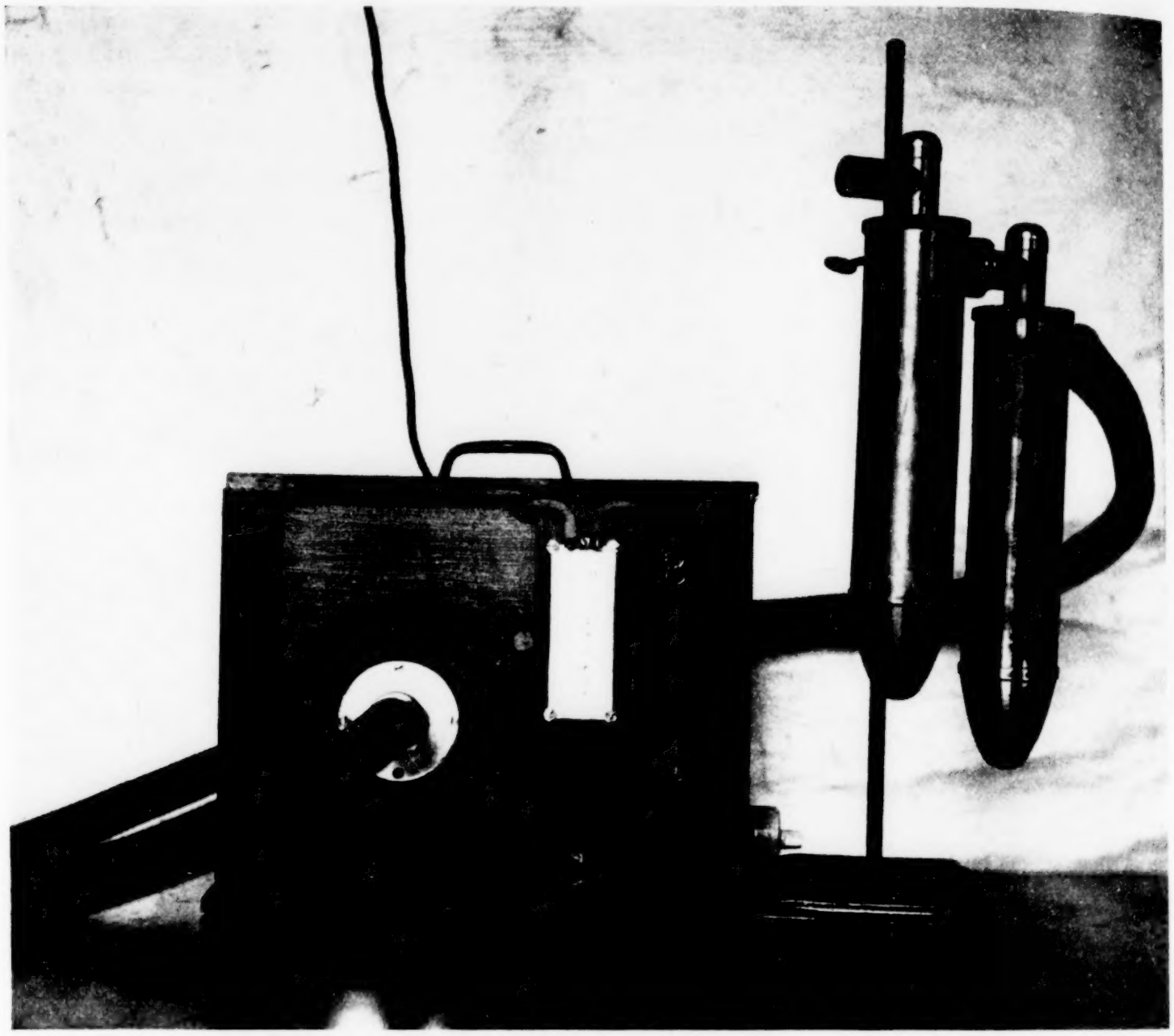

FIG. 2.—Front view of dust sampler, showing two units in series connected to intake of fan by vacuum cleaner tubing. Note also scale for measuring rate of flow on vertical manometer and slide control of rheostat.

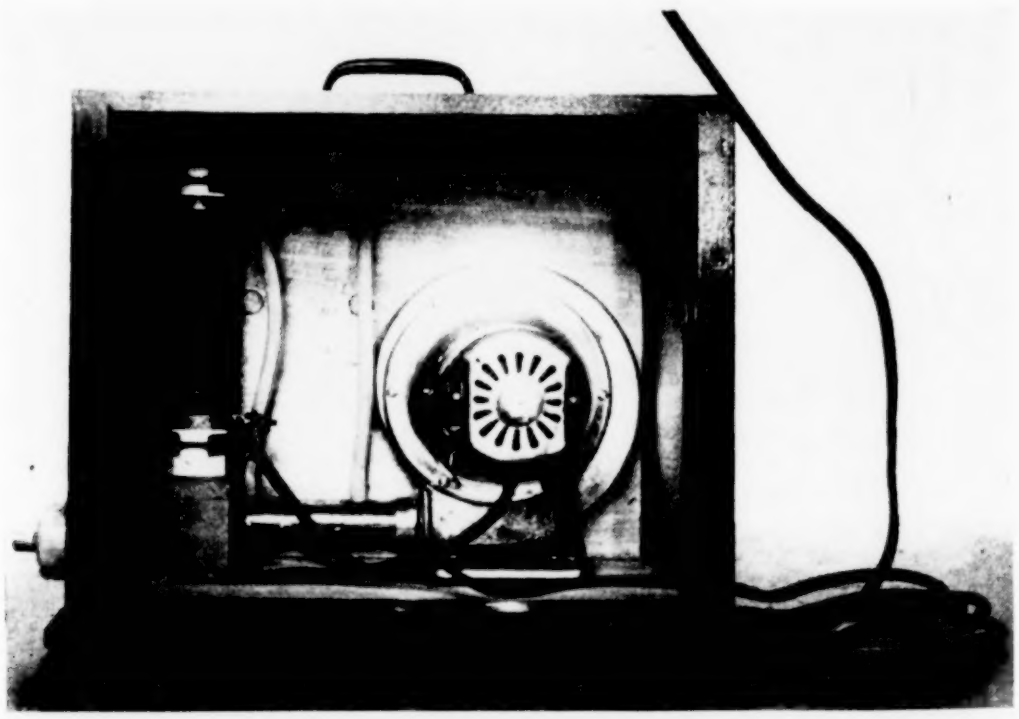

FIG. 3.—Rear view of box in which suction-fan orifice meter and rheostat are mounted. Fan and orifice meter are removed by taking out two screws on base of fan support.

Since our original description appeared, certain alterations have been made in the apparatus and improvements suggested by others have been incorporated. The interest shown in the original apparatus and the subsequent improvements which have been made seem to warrant the publication of a brief description of the modified form.

In this apparatus, contact between the dust particles and the wetting medium, water, is secured by the bubbling arrangement shown in Figure 1. In the original apparatus, a portion of the bubbler was made of glass, but for routine field work a metal apparatus is more satisfactory. That shown in the illustration is constructed of nickel-plated brass, and all parts are interchangeable on the various units. Also two or more units can be connected in series, as shown in Figure 2—a method which is convenient when very fine dust particles are encountered, because an index of the efficiency of collection and of the size distribution of the particles in the air can be obtained from the relative amounts of dust caught in the two units. This was discussed in detail in our original paper.

The spiral entrainment separator (Fig. 1) is an essential feature of this sampler. Without some such device, high rates of flow cannot be maintained without entrainment losses.

For drawing air through the dust samplers, a vacuum cleaner motor fan (see Figs. 2 and 3) is used, and the rates of air flow are measured on a small orifice meter (Fig. 4) on the exhaust side of the fan.

The fact that air flows of 250 to 300 liters per minute are possible with this apparatus is sufficient evidence that the resistance to flow is slight. This in turn permits the use of a light vacuum cleaner motor, running on

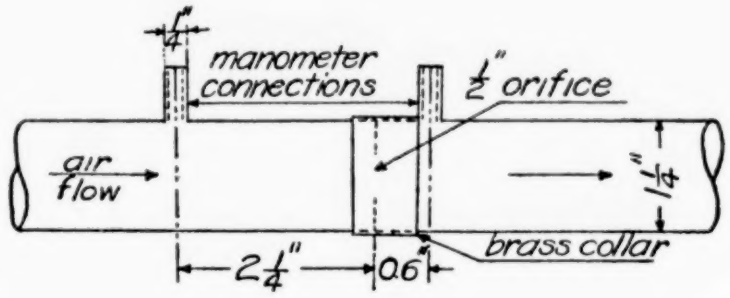

FIG. 4.—Detail of ½-inch orifice meter.

110 volts, alternating or direct current, and the controlling of the rate of air flow by a slide wire rheostat (Fig. 3) on the motor. The vacuum cleaner tubing increases the resistance to air flow, but enables the operator to place the sampling tubes within 10 feet of the box in which the suction fan and the orifice meter are mounted. When samples are to be taken at levels well above the floor, this is often convenient.

Compressed-Air Driven Ejectors for Suction

In many parts of mines and quarries, electric current is not available, but compressed air is supplied for operating pneumatic tools at pressures in the neighborhood of 75 pounds per square inch. In such places, Warren and Read (3) have suggested the use of the Kotzé ejector, actuated by compressed air, as the source of suction. We have found that the Hancock ejector[1] (Fig. 5), obtainable in this country at any large plumbing-supply house, serves this purpose satisfactorily. The ordinary steam actuated "suction tees," used for withdrawing

[1] Made by The Hancock Inspirator Co., Boston and New York.

water from sumps, are less expensive, but, if run on compressed air, require very large volumes to produce strong suction and therefore are not so well adapted to this work.

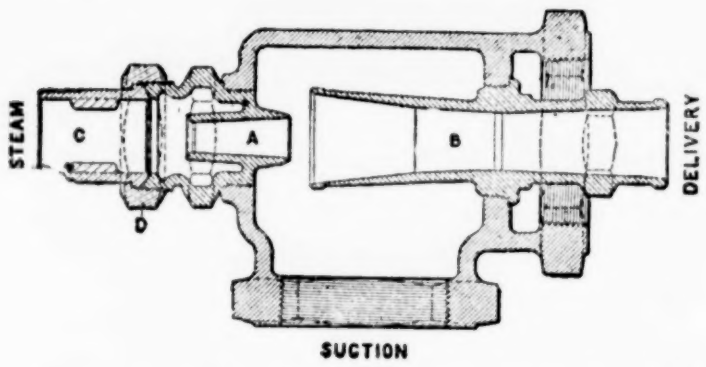

FIG. 5.—Hancock ejector, size 3. This ejector has ample capacity to draw well over 12 cubic feet per minute.

The amount of air drawn by a compressed-air driven ejector depends on the volume of air flowing through, since it is this flow that supplies the suctional force. Consequently, the rate at which air is drawn by an ejector through dust sampling apparatus can be controlled very accurately by a valve on the air line supplying the ejector. The Hancock ejectors, size 3, have ample capacity for drawing air at 300 liters per minute through two of our sampling tubes, 10 feet of vacuum cleaner tubing, and an orifice meter. Furthermore, they can be run very satisfactorily on air pressures as low as 25 pounds per square inch.

Constant Flow Regulator

In a recent personal communication, Mavrogordato suggested that a constant flow regulator in connection with an ejector would be useful in sampling dust in mine air. The apparatus could be started by the shift boss, set for a given rate, and turned off after a specific length of time.

With ejectors as the source of suction, constant suctional force depends on a supply of air at constant rates and therefore at constant pressures. In laboratory work, apparatus for pressure control of air blown through small ejectors is very simple and can be adapted satisfactorily from the Oberfell and Mase regulator (4). In large apparatus drawing 10 or 12 cubic feet per minute, the laboratory regulators are of little use. Mavrogordato has pointed out to us that variations of as much as 40 pounds in the high pressure are not uncommon in mines, so that the duty required of a flow regulator for our apparatus is both severe and exacting.

The Watts reducing valve,[2] which operates on the combined spring-diaphragm principle, has been found to give satisfactory results, and is guaranteed by the makers to deliver air at any desired low pressure, such as 25 pounds, with a maximum variation of 2 pounds. To test this valve under field conditions, it was placed in a ½-inch air line with valves and gages appropriately arranged to simulate working conditions in a mine. The ejector was connected to the low pressure side, 25 pounds, and the suctional force measured by an orifice meter. With a 50 per cent. change in the high pressure, *viz.*, from 80 to 40 pounds, the change in rate of air flow through the orifice meter was about 4 per cent.—an amount easily read on the manometer of the orifice meter, but of doubtful importance in routine sampling. The objection to the Watts type of regulator is that it weighs 19 pounds, so that its use would be limited to locations where frequent samples were to be taken over a con-

[2] Sold by Walworth Manufacturing Co., Boston.

siderable period of time. Whether this regulator will prove satisfactory in routine field work, we are not yet in a position to say.

Discussion of the Dust Sampler

Considering the apparatus from the viewpoint of the field worker, the following disadvantages are to be noted: (*a*) Care is required in cleaning out the collected dust; (*b*) the apparatus is unsuited to the determination of fumes like freshly burned ZnO, or smokes like tobacco, which are difficult to wet with water; (*c*) the water evaporated by bubbling air through the apparatus must be replaced; and (*d*) the water freezes if the wet bulb temperature of the atmosphere reaches 32° F.

The advantages of the apparatus are: (*a*) Samples of dust are collected at rates as high as 300 liters per minute, at gravimetric efficiencies of 95 per cent. or more; (*b*) the resistance to air flow is low enough to permit the use of light vacuum cleaner motor fans, the speed of which can be controlled by rheostat; and (*c*) the total weight is about 25 pounds, when the vacuum cleaner motor, mounted as in Figure 2, is used, and 10 pounds, with the Hancock ejector.

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THE RECOVERY OF SMALL AMOUNTS OF ZINC FROM BIOLOGIC MATERIAL ASHED BY THE INCINERATION PROCESS*

PHEBE K. THOMPSON, M.D.

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

INTRODUCTION

THE first step in the procedure for the zinc analysis of biologic material is the destruction of the organic matter. This may be accomplished either by incineration or by oxidizing with chemicals such as sulphuric and nitric acids. The latter method, known as "wet ashing," is the most commonly used, but it has several decided disadvantages, chief among which are the time, care, and attention required to oxidize completely the large amounts of organic material frequently encountered, and the necessity for using reagents which are difficult to purify should they be found to contain zinc. The incineration method is much preferable because it not only eliminates the use of these reagents, but it also makes a great deal less demand on the analyst's services—a very important factor where there are long series of routine analyses to be done.

It is essential, however, that the saving of time and trouble be not at the expense of accurate results. In the incineration process of ashing, when carried out in an electric furnace, temperatures can be made to range from about 400°C. (black heat) up through the various stages of red heat, to as high a temperature as desired. Zinc has a boiling point of about 920°C. and shows the following vapor pressures at temperatures from 419.4°C. up to 906.5°C. (1):

Temperature °C.	*Vapor Pressure* *mm. Hg*
419.4	0.151
490.7	1.069
544.5	3.687
588.8	9.051
641.1	23.02
720.4	81.42
836.0	356.20
905.7	760.00[1]
906.5	760.00

[1] One atmosphere.

Naturally the question of the volatilization of zinc at the comparatively high temperatures involved has to be taken into account. Without any definite data on the subject, one would be inclined to think that there was considerable risk of losing zinc in this way. There is, therefore, some doubt in the minds of certain observers regarding the accuracy of incineration as a method of ashing when applied to zinc recoveries, as may be seen from Table 1, which gives the opinions of workers who have used incineration or who refer in any way

* Received for publication April 15, 1925.

TABLE 1.—OPINIONS OF INVESTIGATORS IN REGARD TO LOSS OF ZINC DURING INCINERATION OR HEATING

INVESTIGATOR	METHOD OF INCINERATION	REMARKS
Birckner (2)	Incineration in muffle at low heat.	Warns analyst to guard against loss of zinc during ignition.
Bodansky (3)	Oxidation with sulphuric and nitric acids; then ignition over Bunsen flame at dull red heat.	.....
Brand (4)	.....	Remarks that care has to be exercised to prevent loss of zinc if incineration is used.
Brandl and Scherpe (5)	Incineration used for feces.	State that the only method then considered permissible was wet ashing, as incineration or charring was supposed to cause loss of zinc, but lately it had been shown that with certain precautions organic material could be charred without loss of zinc.
Browne (6)	Dry ashing.	.....
Hertwig (7)	Incineration at faint red heat.	Obtained good results compared with method of Association of Official Agricultural Chemists (wet ashing).
Janke (8)	Oxidation of the char with nitric and sulphuric acids; then incineration at incipient red heat for four hours.	No loss of zinc at this temperature.
Lechartier and Bellamy (9)	Used carbonization and extraction with nitric acid for vegetable material.	.....
Legler (10)	Carbonization and extraction with hydrochloric acid.	Four experiments to show that results are as good as with wet ashing. There is no volatilization of zinc on carbonizing organic material, as is very likely to occur if the temperature is raised to strong ignition heat.
Lehmann (11)	Dry ashing in presence of nitrates.	States that he did experiments (not given) to show that even with zinc in the form of zinc chloride there is no loss to be feared.
Mayer (12)	Careful ignition; then heated strongly in Bunsen flame.	.....

TABLE 1.—*Continued*

INVESTIGATOR	METHOD OF INCINERATION	REMARKS
McGeorge (13)	Incineration of the char at low red heat.	.....
Mehurin (14)	Incineration at incipient red heat (500° to 550°) for five hours.	No error if left for a longer time.
Mendel and Bradley (15)	Ashed microscopic sections at red heat. Presumably used this heat for zinc analyses.	.....
Munson (16)	Charred with sulphuric acid; then ignited to ash in a muffle, using nitric acid if necessary.	.....
Nicolardot (17)	Calcination.	.....
Niederstadt (18)	Carbonization and extraction with hydrochloric acid, followed by wet ashing.	Wet method thought to be safer, yet the volatility of zinc not such as commonly supposed. Cites an experiment to show that there is no loss of zinc when organic substance is carbonized. The dry method is in discredit owing to discordant analyses by the same person on the same material (dried apples). This is often due to inaccurate sampling.
Pfyl and Samter (19)	On account of the nature of their work, the inference is that they used dry ashing.	.....
Phillips (20)	Incineration at low red heat, not high enough to fuse the chlorides.	.....
Salant *et al.* (21)	Oxidation with sulphuric and nitric acids; then incineration at low red heat.	.....
Salkowski (22)	.....	Used wet ashing, but did a few experiments on dry ashing with nitrates and also on incineration (no temperature given), as he thought the volatility of zinc might be overestimated. States that incineration is unquestionably the most convenient way, and that he has little doubt that it is quantitative, but that more research needs to be done to prove this.
Seiler (23)	Dry ashing.	.....

TABLE 1.—*Concluded*

INVESTIGATOR	METHOD OF INCINERATION	REMARKS
Severy (24)	Used Bodansky's modification of Birckner's method. The inference is that incineration at dull red heat was the method of ashing.	.....
Weitzel (25)	Dry ashing for materials with light ash.	.....
Wiley (26)	Incineration at low temperature after charring and extracting.	.....
Delezenne (27)	Used technic of Bertrand (wet ashing).	Animal tissues poor in alkaline salts are very difficult to ash. There is danger of overheating if incineration is used.
Hiltner and Wichmann (28)	Used wet ashing followed by gradual heating in a muffle below red heat at first.	It is not feasible to destroy organic matter directly by burning owing to danger of losing both copper and zinc by volatilization.
Lourie (29)	.....	Obtained higher results with wet ashing than when he used incineration at low red heat (McGeorge method).
Wolff (30)	.....	Cod liver oil ashed in electric furnace (temperature not stated) yielded no zinc. By wet ashing 23 to 40 mg. of zinc per kilogram was found.

to temperature effects in zinc recoveries.

These workers may be roughly divided into three classes—*viz.*, those who use incineration without reference to a definite temperature, leaving others to nfer that they believe that no zinc is lost by volatilization at the heats generally used for ashing; those who use incineration, with mention of precautions to guard against loss of zinc; and those who do not use incineration at all, fearing that the risk of loss of zinc is too great.

In none of the articles cited in Table 1 (with the possible exception of a few observations by Hertwig, Legler, Lehmann, Niederstadt, Salkowski, Lourie, and Wolff) is there any reference to a systematic series of experiments to uphold the views of the authors. There is evidently need for a rather extensive study of the question in order to clarify the situation, and it is the object of this present work to supply such information.

Experimental Work

Biologic Material Used.—For this investigation two groups of organic material were selected. One group was representative of the material usually dealt with in zinc researches on animals and man—*viz.*, urine, feces, muscle, and blood; the other group was chosen for its minimal zinc content—*viz.*, flour, soluble starch, vinegar, and ashless filter paper, all of which, in the amounts used for an analysis, did not contain sufficient zinc to give a positive test.

Forms of Zinc Used.—Metallic zinc was used in the form both of zinc dust and of pure sheet zinc, in case metallic zinc might be formed by reduction during the incineration of biologic material.

Zinc oxide, zinc chloride, and zinc sulphate were considered to be fairly typical of the forms in which zinc might be encountered in organic matter. Zinc sulphate, being a relatively stable salt, was investigated both with and without organic material in order to study thoroughly its behavior, with the idea that if other zinc compounds gave trouble they could be converted to the sulphate during ashing. Zinc chloride was similarly treated in order to study the behavior of a zinc salt which has a relatively low boiling point —*viz.*, 700° to 730°C.

Zinc linoleate, zinc tungate, zinc resinate, zinc stearate, and zinc acetate were chosen to be representative of organic zinc compounds—the last named being selected also because of its tendency to sublime in vacuo (31).

Analytic Procedure

a. Preparation for Incineration.—The zinc sulphate and zinc chloride were each used as standard solutions made from weighed pure zinc oxide dissolved in the least possible amount of the corresponding acid and diluted to volume with conductivity water, so that 10 c.c. contained 1 mg. of zinc. The desired amount of solution, usually 25 c.c., was measured from a burette into a porcelain evaporating dish containing the weighed homogeneous organic material. The whole was well mixed, dried in a gas oven, and then charred on a hot plate. Zinc chloride and zinc sulphate were also used in a number of cases in the isolated condition. Here the measured solutions were simply evaporated to dryness before being put in the furnace. The other forms of zinc, previously analyzed for zinc content by a wet-ashing method, were added to the organic material in accurately weighed amounts; then they were mixed and charred.

b. Incineration and Extraction.—The prepared samples were placed in an electric muffle furnace and left for varying lengths of time at different temperatures until the work had proceeded far enough to enable us to select a standard of 450°C.

Furnace temperatures were measured with a pyrometer (Pyrovolter). This is an instrument which records heat directly, as the electromotive force developed by a temperature difference between two junctions in a thermocouple. One junction is kept constantly at 0°C. in a thermos bottle containing melting ice; the

other is placed where the temperature is to be measured—in this case, in the electric furnace directly over the material being incinerated. It was found that black heat just before red appeared was about 450°C.; incipient red, 500°C.; dull red, 550°C.; and full red, 650°C., etc.

Some materials, like muscle, take much longer to ash than others, but in general the dishes were removed from the furnace after heating at 450°C. for about four hours. When cool, the residues were extracted with 5 to 10 c.c. of 1:1 hydrochloric acid, covered with hot water, allowed to stand, and then filtered; this extraction was then repeated. The filter paper and contents were next returned to the dish, dried, charred, and put into the furnace for final ashing. If the first extraction was done thoroughly, so that the inorganic salts were well washed out, there was usually no difficulty in completing the second ashing of the most refractory material in four to six hours. Final extraction was performed as before, with the exception of one addition only of hydrochloric acid, which brought everything into solution except perhaps a little silicious residue. It is essential that the carbon be completely burned up, as a few seemingly insignificant particles retain a surprising amount of zinc. In the case of materials such as blood and feces, which contain considerable quantities of iron, the final ash has to be heated with hydrochloric acid in order to get the iron into solution.

c. Method of Analysis.—The reagents, including the distilled water, were all tested for zinc. It was found necessary to purify only the hydrochloric acid, which was done by distillation. The pyrex glassware and the filter paper used were analyzed and found to contain no zinc.

An accurate method of analysis is very essential for significant results. The following procedures were found to be satisfactory in this respect:

1. For Starch, Flour, and Filter Paper.—In these materials the heavy metals were not present in sufficient amount to cause a precipitate with hydrogen sulphide in mineral acid solution. The hydrochloric acid solutions of the ash, made up to about 70 c.c. with water, were therefore neutralized with ammonium acetate (no phosphate was precipitated), well saturated with hydrogen sulphide, and allowed to stand overnight. The solutions, still smelling of hydrogen sulphide (if they did not, they were resaturated), were filtered the next morning. The zinc sulphide precipitates were washed with hydrogen sulphide water acidified with acetic acid, dissolved off the filter paper with 5 c.c. of 1:1 hydrochloric acid, and evaporated to dryness; 10 c.c. of N/10 sulphuric acid was then added, evaporated to dryness, and fumed off; 5 c.c. of N/10 sulphuric acid was added and the whole made up to 25 c.c. with water, in a volumetric flask.

2. For Feces and Blood.—Considerable modification of the method was necessary for these materials, owing to their high iron content. When the hydrochloric acid solution of the ash is neutralized preparatory to precipitating zinc sul-

phide in acetic acid solution, a heavy precipitate of iron phosphate occurs. Iron has to be removed in any case, as it interferes with the final stage of the analysis, but its appearance at this point necessitates doing so in a very tedious manner.

Weitzel's method (25) was in part adopted here—*viz.*, the hydrochloric acid solution of the ash was oxidized with bromine water, in order to change the iron from the ferrous to the ferric condition, cooled, neutralized with 25 per cent. sodium hydroxide, and acidified with acetic acid, a little sodium phosphate being added to insure against any lack of phosphate ion. The ferric phosphate precipitate was filtered and washed; and as it always adsorbs some zinc phosphate, it was dissolved off the filter paper with hydrochloric acid and reprecipitated as before, except that ammonium acetate was used for neutralizing instead of sodium hydroxide. (The latter precipitates ferric hydroxide instead of ferric phosphate in such small volumes of solution, in spite of the addition of sodium phosphate.) The number of times this process has to be repeated depends on the size of the precipitate. For the amount of iron phosphate formed from one day's feces, two reprecipitations are sufficient; for the amount contained in, for instance, 200 c.c. of blood, three or even four reprecipitations may be necessary.

The resulting clear filtrates were acidified with hydrochloric acid and evaporated down to 200 c.c. volume. When cool, they were neutralized with ammonium acetate and saturated with hydrogen sulphide. The heavy metals are thus brought down along with the zinc. If they are not present in sufficient quantity, a few drops of 2 per cent. copper acetate are added to the solution. The heavy metal sulphides adsorb the zinc sulphide and cause its precipitation to be more complete when it is present in small amounts. The sulphide precipitates were next filtered and washed with hydrogen sulphide water. The filter papers and contents were then digested in a conical beaker with 15 c.c. of 1:1 hydrochloric acid and three to four drops of nitric acid; when they became a clear yellow color, they were diluted with about 25 c.c. of water, filtered, and thoroughly washed with hot water. The filtrates were then saturated with hydrogen sulphide and the resulting heavy metal sulphides filtered and washed at once with distilled water which had been boiled half an hour to expel air. This was used instead of hydrogen sulphide wash water, as with the latter there was some trouble due to copper sulphide appearing in the filtrate.

The filtrates, evaporated to about 75 c.c. volume, were then neutralized with ammonium acetate, saturated with hydrogen sulphide, and proceeded with as in the case of flour and starch.

3. For Muscle, Urine, and Vinegar.—In muscle and vinegar the amount of iron phosphate formed was so small that no reprecipitations were necessary.

In urine the precipitate which formed on neutralizing the hydrochloric acid ash solution cleared up on the addition of acetic acid; this eliminated all phosphate precipitations. In each of these cases copper

acetate was added to adsorb the zinc sulphide.

4. Estimation of Zinc Content.—The zinc content of the samples prepared as above was estimated by the turbidimetric method. This consists of a comparison of the turbidities produced by different amounts of zinc with potassium ferrocyanide in faintly acid solution.

It is absolutely essential for this comparison that the samples be of equal salt concentration, as the turbidity is noticeably affected by the degree of acidity of the portion analyzed. With this in view, the method has been recently modified by Dr. L. T. Fairhall and Miss J. L. Finn (32), and is as outlined below.

Suitable portions of the samples to be analyzed were taken to be compared, in carefully selected 50-c.c. Nessler tubes, with zinc sulphate standards ranging from 0.025 to 0.5 mg. of zinc. In order to make the salt content of all tubes equal, the amount of N/10 sodium hydroxide necessary to neutralize the most acid portion (one drop of phenolphthalein as indicator) was determined and this amount added to all tubes, standards included. Then all samples were acidified with N/10 sulphuric acid to one drop excess. One cubic centimeter of saturated solution of N/10 sulphurous acid was added to each to prevent the development of a green color which is liable to occur otherwise; boiled water (20°C.) was added to each tube until it contained about 45 c.c. of fluid; 1 c.c. of freshly prepared 2 per cent. potassium ferrocyanide was then added, and finally water to the 50 c.c. mark. The tubes were well shaken and put in a dark place for twenty minutes. At the end of this time their turbidities were compared against a dark background. From the result, the amounts of zinc in the unknowns were calculated by a simple multiplication factor.

The maximum error in the whole series of final results obtained by the foregoing rather involved procedure was about ±8 per cent. or ±0.2 mg. where 2 to 5 mg. of zinc were used. This method is not reliable for amounts of zinc in excess of 10 mg., but for the object of this experiment—the recovery of amounts of zinc in the neighborhood of 2.5 mg.—it served the purpose admirably.

Experimental Results

Zinc (see Table 2).—Recoveries of metallic zinc, incinerated with organic material, were good, indicating that whenever metallic zinc is formed by reduction no loss by volatilization will occur on ashing at black heat.

Zinc Oxide (see Table 3).—When heated with organic material which would reduce it to metallic zinc, zinc oxide suffered no loss by volatilization even when heated to 650°C.

Zinc Chloride (see Table 4).—When used alone, zinc chloride gave very variable results as would be expected. In a few cases recoveries were good, apparently because the zinc chloride was oxidized to zinc oxide—the residue on the dishes was greenish yellow where hot—which was not driven off at the temperatures involved.

In the presence of organic material, however, the recoveries of zinc chlo-

ride were satisfactory. Probably the organic material reduces the chloride,

TABLE 2.—RECOVERY OF METALLIC ZINC ADDED TO ORGANIC MATERIAL

FORM OF ZINC	TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED	ORGANIC MATERIAL
	°C.	hrs.	mg.	mg.	
Pure sheet zinc	450	4	1.9	1.9	Flour.
	450	4	2.9	2.8	
	450	4	4.1	4.1	
	450	6	2.4	2.5	
	450	6	3.5	3.5	
	450	6	4.3	4.6	
	450	6	4.5	4.6	
	450	6	2.0	2.0	Filter paper.
	450	6	2.1	2.0	
	450	6	3.6	3.5	
	550	6	2.1	2.3	
	550	6	2.3	2.5	
	650	6	2.4	2.5	
	650	4	2.6	2.5	
Zinc dust	450	10	3.0	3.1	Muscle.
	450	10	3.0	3.1	
	450	10	3.0	3.1	
	450	10	3.0	3.1	

TABLE 3.—RECOVERY OF ZINC OXIDE ADDED TO ORGANIC MATERIAL (FILTER PAPER)

TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED
°C.	hrs.	mg.	mg.
450	4	2	1.9
550	6	2	1.9
550	6	2	1.9
600	4	2	1.7
650	6	2	1.9
650	6	2	1.9

TABLE 4.—RECOVERY OF ZINC CHLORIDE WITH AND WITHOUT ORGANIC MATERIAL

MATERIAL	TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED
	°C.	hrs.	mg.	mg.
Zinc chloride alone	450	8	2.5	0.6
	450	8	2.5	0.6
	450	8	2.5	0.8
	450	8	2.5	0.8
	450	5	2.5	1.6
	450	5	2.5	1.6
	450	5	2.5	1.2
	450	5	2.5	1.2
	450	5	2.5	2.5
	450	5	2.5	2.3
	450	5	2.5	2.0
	450	5	2.5	2.0
	450	5	2.5	2.2
	600	3	2.5	0.0
	600	3	2.5	0.0
	600	4	2.5	0.0
	600	4	2.5	0.0
	600	4	2.5	0.3
	600	4	2.5	0.3
	600	1	2.5	0.3
	650	2	2.5	0.0
	650	2	2.5	0.0
	800	2	2.5	2.5
	800	2	2.5	1.9
	800	2	2.5	0.3
	800	2	2.5	0.3
	800	4	2.5	0.3
	800	4	2.5	0.6
	800	4	2.5	2.2
	800	4	2.5	2.2
Zinc chloride and flour	450	4	2.5	2.4
	450	4	2.5	2.5
	450	4	2.5	2.5
	450	4	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5

TABLE 4.—*Continued*

MATERIAL	TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED
	°C.	hrs.	mg.	mg.
Zinc chloride and filter paper.....	450	7	2.5	2.6
	450	7	2.5	2.6
	450	7	2.5	2.6
	450	7	2.5	2.6
	450	7	2.5	2.5
	450	7	2.5	2.5
	550	5	2.5	2.2
	550	5	2.5	2.2
	550	6	2.5	2.4
	550	6	2.5	2.4
	650	5	2.5	2.5
	650	5	2.5	2.5
	650	6	2.5	2.2
	650	6	2.5	2.4
Zinc chloride and urine.....	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
Zinc chloride and blood.....	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	2.5	2.5
Zinc chloride and muscle.....	450	10	1.0	1.0
	450	10	1.0	1.0
	450	10	2.5	2.7
	450	10	2.5	2.7
	450	10	2.5	2.7
	450	10	2.5	2.4
Zinc chloride and feces.....	450	8	3.0	3.0
	450	8	2.5	2.5
	450	8	2.5	2.5
	450	8	10.0	10.2
	450	8	10.0	10.2
	450	8	10.0	10.2

and the tendency to volatilize is checked.

Zinc Sulphate (see Table 5).—Zinc sulphate, when used alone, underwent no significant loss, even when heated to 800°C. Zinc sulphate with organic material also gave good recoveries.

TABLE 5.—RECOVERY OF ZINC SULPHATE WITH AND WITHOUT ORGANIC MATERIAL

MATERIAL	TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED
	°C.	hrs.	mg.	mg.
Zinc sulphate alone.	450	7	2.5	2.5
	450	7	2.5	2.5
	450	7	2.5	2.5
	450	7	2.5	2.3
	550	3	2.5	2.5
	550	3	2.5	2.7
	550	3	2.5	2.7
	550	3	2.5	2.7
	800	2	2.5	2.5
	800	2	2.5	2.5
	800	3	2.5	2.5
	800	3	2.5	2.5
	800	3	2.5	2.5
	800	4	2.5	2.7
	800	4	2.5	2.7
	800	4	2.5	2.5
	800	4	2.5	2.5
Zinc sulphate with blood.....	450	8	2.5	2.5
	450	8	2.5	2.4
	450	8	2.5	2.4
Zinc sulphate with soluble starch.....	450	3	2.5	2.5
	450	3	2.5	2.5
	450	3	2.5	2.5
	650	4	2.5	2.7
	650	4	2.5	2.7
	650	4	2.5	2.5
	650	4	2.5	2.5
	650	4	2.5	2.7

Organic Zinc Compounds (see Table 6).—With organic matter, recoveries of organic zinc compounds were good, even in the case of zinc acetate.

In Tables 2 to 6 the zinc recoveries with blood, muscle, feces, and urine were corrected for normal zinc content, as follows:

Material	*Amount*	*Normal Zinc Content*
Blood	200 c.c.	0.4 mg.
Muscle (minced)	50 gm.	1.7 mg.
Feces (liquid)	200 gm.	8.8 mg.
Urine	500 c.c.	0.8 mg.

The filter paper, flour, starch, and vinegar were zinc free in the amounts used, which were as follows:

Material	*Amount*
Filter paper	6 sheets ashless
Flour	10 gm.
Soluble starch	10 gm.
Vinegar	100 c.c.

As the heating in most of these cases was prolonged for several hours, every opportunity was given for loss of zinc; yet this did not occur to any appreciable extent. There is the possibility of the intervention of adsorption phenomena, for every condition is favorable—charcoal is freshly formed from the incineration of the organic material and, owing to the temperature, must be in an activated condition; at any rate, it clings tenaciously to traces of zinc which are not finally recovered until the coal is completely burned.

Dr. R. E. Lutz (33), working in this laboratory, has further corroborated the accuracy of this method of incineration by his zinc recovery experiments. The analyses were done by his urobilin method, which detects zinc in amounts of 0.01 to 0.1 mg.

TABLE 6.—RECOVERY OF ORGANIC ZINC COMPOUNDS ADDED TO ORGANIC MATERIAL

ORGANIC ZINC COMPOUND	TEMPERATURE	TIME HEATED	ZINC ADDED	ZINC RECOVERED	ORGANIC MATERIAL
	°C.	hrs.	mg.	mg.	
Zinc linoleate	450	10	3.0	3.1	Muscle.
	450	10	3.0	3.1	
	450	10	3.0	3.1	
	450	10	3.0	3.1	
Zinc stearate	450	10	3.1	3.1	
	450	10	3.1	3.1	
	450	10	3.1	3.1	
	450	10	3.1	3.1	
Zinc tungate	450	10	3.1	3.1	
	450	10	3.1	3.1	
	450	10	3.1	3.1	
	450	10	3.1	3.1	
Zinc resinate	450	10	3.0	3.1	
	450	10	3.0	3.1	
	450	10	3.0	3.1	
	450	10	3.0	3.1	
Zinc acetate	450	6	2.5	2.5	Vinegar.
	450	6	2.5	2.5	
	450	6	2.5	2.5	
	450	6	2.5	2.5	
	450	6	2.5	2.5	

Conclusion

Biologic material containing zinc in small amounts may be easily and safely ashed by incineration at 450°C.

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NECROSIS OF THE JAW IN WORKERS EMPLOYED IN APPLYING A LUMINOUS PAINT CONTAINING RADIUM*

WILLIAM B. CASTLE, M.D., KATHERINE R. DRINKER, M.D., AND CECIL K. DRINKER, M.D.

From the Department of Physiology, Harvard School of Public Health, Boston, Mass.

THE investigations which are reported in this paper were begun at the request of the president of the company involved, and were conducted in the factory of this company and in the Harvard School of Public Health. It would have been impossible to make the observations we are placing on record without the complete co-operation of the executives and employees of the corporation in question and it is a pleasure to acknowledge this co-operation in a thorough examination, which, when coupled with the publication of the results, confronts the medical profession with a most interesting and novel problem.

SUMMARY OF CASES OF NECROSIS OF THE JAW

Our work began following receipt of a letter dated March 12, 1924, giving an account of two cases of necrosis of the jaw—one fatal case and one existing case, supposedly on the mend.

Careful inquiries and investigations made during two visits to the plant have enabled us to trace the following instances of chronic disease processes occurring in the jaw-bones of employees engaged in the application of luminous paint.

CASE 1.—Miss A., employed for four years and four months, ending in 1922, developed a necrosis of the jaw and later died.

CASE 2.—Miss B., employed for approximately two years and seven months, ending in 1921, developed, following the extraction of a tooth, a rapidly progressing necrosis of the jaw, not improved by curetting eight or nine times. Miss B. finally died as a result of this disease process.

CASE 3.—Miss C., employed from 1917 to 1920, inclusive, developed, following the extraction of a tooth, about December, 1923, progressive necrosis of the jaw, necessitating the removal of much of her left upper jaw and two blood transfusions. This patient died of chronic sepsis late in 1924, approximately one year after the extraction of the tooth.

CASE 4.—Miss D., employed for a period of six and one-half years, ending in 1923, began to fail in health three years before cessation of employment. Her symptoms were extreme fatigue and weakness with pallor. She continued her work in spite of increasing ill health and in October, 1923, developed a toothache with local swelling of the face. In December, 1923, she had an upper and a lower right molar pulled, a piece of decayed bone coming out with one of these teeth. She then stopped work. Normal healing of the jaw did not ensue; instead, a discharge of pus began and persisted. Later, two other teeth at some distance became affected and were extracted. When examined in May, 1924, she had, in addition to the process in the lower jaw, a

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new sinus in the upper jaw communicating with the antrum, as shown by X-rays. Her appearance was very bad; she had lost much weight and was very pale. Her blood, on microscopic examination, showed a profound anemia. She complained of pain in the bones of her face, had considerable inconvenience from the discharge of foul pus in her mouth and was forced to spend much of her time in bed. She said, however, that of late she had felt a little better—a statement not in accord with her appearance nor with the new septic process. At the time of examination this girl was in an extremely serious condition.

X-ray films made May 7, 1924, showed necrosis of the right upper maxilla with a great deal of clouding of the antrum and an apparent tendency to extend into the nose. The necrosis was not yet great enough to cause loss of all the teeth, but the condition of the antrum and the tendency of the process to extend upward toward the skull made one fear the possible onset of meningitis.

Case 5.—Miss E., who left employment in 1919, had a left lower molar extracted in 1923. The wound apparently healed normally. Six months later a sinus appeared at the site of the extracted molar and drained pus profusely for some months. X-rays taken after admission to a local hospital in March, 1924, showed evidence of a chronic infectious process in the jaw in the region of the extracted tooth. This patient left the hospital after five days, unrelieved and with a diagnosis of chronic osteomyelitis of the jaw, possibly due to phosphorus poisoning. She was, however, reported in May, 1924, to have recovered satisfactorily.

Here, then, is a series of five cases of necrosis of the jaw—necrosis not at all like the ordinary infections of the jaw which do occasionally follow the extraction of a tooth. Instead of a localized process which heals either of itself or after the establishment of drainage, we have a chronic, progressive rotting away of the bone, which is essentially different from an ordinary infectious process or from tuberculosis of the bone, but resembles very closely the necrosis of the jaw resulting from phosphorus poisoning. In our opinion, so great an incidence among these employees of this unusual disease process in the jaw cannot be a coincidence but must be dependent on some type of bone damage occasioned by the employment.

Analysis of Possible Toxic Agents

In view of the excellent general hygienic conditions of the work in the particular factory, it seemed at once advisable to study the special ingredients used in the luminous material.

The base of the luminous paint contains no phosphorus but consists of a luminous zinc sulphide containing minute traces of copper combined with small amounts of radium bromide, probably changed later into radium sulphate. The radium bromide is intimately mixed with the zinc sulphide. The vehicle is varied and the paint is applied with fine brushes.

As we learned from the dial painters that until six months before our investigation it was their universal practice to point their brushes in their mouths, we have considered the possibility of brushes or of vehicle as a source of difficulty. Bacteriologic studies of twelve brushes have been negative for anthrax. The bacteria cultured from the brushes were Bacillus subtilis, Staphylococcus albus, and a gram-negative nonsugar fermenting bacillus—harmless air-borne organisms which may be found normally in the mouth. Gum Acacia, the usual vehicle for the luminous material, is of course entirely nontoxic by mouth. We may now

consider the constituents of the luminous powder itself.

Zinc.—Zinc, in the opinion of practically all recent authorities, is in itself nonpoisonous (1) (2). So-called "poisonous" actions are due to the local irritant effects of soluble salts. Zinc sulphide is an insoluble salt and has never been the cause of any kind of poisoning. It is not reasonable to suppose that this salt would be readily absorbed or, if so, that it would be toxic in the relatively small quantities involved. We are, fortunately, able to instance additional proof of this in the operations of the New Jersey Zinc Company. In a part of the works in which zinc sulphide is made the employees are exposed to it in large quantities in a finely divided form. They must inhale and swallow it, as well as have a liberal contact with it through the skin. These workers have been observed over many years and exhibit no unusual pulmonary, skin, or digestive disturbances which might be due to local effects; certainly no cases of necrosis of the jaw have occurred as a result of their very ample exposure to zinc sulphide.

The zinc sulphide employed is, to be sure, not identical with that just mentioned. Its molecular state has been changed by "roasting" so that it is photosensitive. It is also, we find, more insoluble than the nonluminous sulphide in common inorganic reagents. This would tend to diminish any possible local effects—of which we found none in the plant under investigation—and make it more difficultly soluble for the organism. Lastly, if it were dissolved and absorbed by the organism it would change its chemical form, becoming probably a chloride or eventually a phosphate, and in this form would be identical with the soluble product from ordinary zinc sulphide that had been absorbed. If such a solubility does take place, the presence of soluble zinc in the organism, even where the exposure is many times greater than at the plant studied, is harmless, judging by the good health of the employees of the zinc sulphide department of the New Jersey Zinc Company and by a large general experience with the problems of zinc poisoning.

Copper.—It is hardly conceivable that the minute traces of copper present in the paint are significant as a toxic agent.

Radium.—There is a great deal of material in the literature on the effects of radium on animals and on men. In individuals working in the manufacture of radium apparatus and in clinical workers with this substance, the important symptoms of overexposure to radium are disturbances of the male and female sex organs, skin changes, and changes in the blood. These changes occur in persons who are exposed to radium externally but not in such a way as to be able to absorb any of the element itself.

Disturbance of menstruation in the female and sterility in the male are clearly recognized. And in the work of Mottram (3) (4), Gudzent and Halberstaedter (5), Williams (6), Pfahler (7), and others there is ample evidence of a disturbance of the blood functions following overexposure to radium. This disturbance consists in a change in the white cells of the blood, a diminution in number and an alteration in the proportions of lymphocytes

and of polymorphonuclear cells. The red cells may also be affected, and there is evidence in some cases of a change in the ability of the bone marrow to manufacture these cells. At least five deaths[1] due to failure of the blood-forming organs have been reported as associated with overexposure to radium or X-rays (7)[2] (8). The presence of changes in the white cells may be uncombined with other damage, and an individual showing these changes may be in good health, but the weight of opinion at present is in favor of regarding the occurrence of even minor deviations from the normal among radium workers as evidence of overexposure to radium. This index has already found a basis in practice in the London Radium Institute, where the blood film is used as a means of determining the need of vacations or of increased protection.

In regard to the distribution and time during which radium in various forms will stay in the body, there is a mass of evidence which is often contradictory. From it clearly emerges the fact, however, that reliable workers have shown that, except for emanation, both soluble and insoluble salts of radium once in the system may remain for a considerable period, even longer than a year in the case of insoluble salts intravenously injected (9) (10) (11).

Pertinent facts in regard to the effect of radium on bone have been demonstrated by other writers. We have found in the literature no reports of cases of necrosis of the bone occurring among radium workers as the result of overexposure to radium during the course of their work. It has been demonstrated experimentally, however, that X-rays, which are similar to but less penetrating than gamma-rays, will delay or prevent the union of a fracture by delaying the normal production of callus (12). Exposure to X-rays will also disturb the growth of bone (13). Gamma-rays themselves, in a local application of radium in the course of treatment of cancer of the tongue, have produced in a sound jaw a necrosis (14) similar to those with which we are concerned, similar even to the extent that in one of the four jaw-bones so radiated, and to all intents normal, necrosis followed only after the extraction of a tooth. That radium, if absorbed, might have a preference for bone as a final point of fixation is to be anticipated from the similar chemical nature of radium, calcium, barium, and strontium. Strontium has been shown to be deposited by replacement of calcium in bone (15) (16), which has for its basic substance a calcified matrix, so it is not surprising to find that a considerable fraction of radium remaining in the body following the intravenous or intramuscular injection of both soluble and insoluble radium salts becomes fixed in the skeleton (17) (18). Intratracheal injections of the luminous paint into cats made by the authors have shown just such a deposition and fixation of radium in the hard bone. Radium

[1] Since the writing of this article other cases of death from pernicious anemia following exposure to radium have been reported. See, for example, Weil and Lacassagne: Pernicious Anemia from Radium. Abstr. from Bull. Soc. méd. d. hôp., 1925, *49*, 535, in Jour. Am. Med. Assn., 1925, *84*, 1786.

[2] The five cases mentioned are summarized in this reference.

once deposited in bone would be in a position to produce peculiarly effective damage. In the first place, all of the weakly penetrating radiation would be absorbed with intense local damage. And, secondly, the more penetrating gamma-rays would be, to a large extent, changed into easily absorbed secondary radiations characteristic of the calcium atom. The effectiveness of a unit of radium inside a bone would be many thousand times greater than the same amount outside of the bone and the soft tissues as well, because of the enormously greater proportion of radiations absorbed in the bone. The alpha particles and many of the beta and gamma-rays from an external source would never take effect in the bone at all, either because of their very distance away from the bone or because of their being absorbed by the soft tissues.

It thus appears as if the only constituent of the luminous material which can do harm must be the radium. The profound effect of radium even in minute quantities on living cells is too well known to require more than mere mention. In addition, experimental evidence is not wanting to show that there may be a selective deposit of radium in bone, and that the effects of radiations of the sort emitted by radium may prevent both bone growth and the repair of fractures. A necrotic process in the jaw-bone itself, like that occurring in the employees with whom we are concerned, has been reported in four instances following the use of radium in the mouth for therapeutic effect on cancer of the tongue.

Conditions Observed at the Plant

We found the girls employed in painting in a large, well-lighted room. The fact that the powder to be used in mixing the luminous paint is issued to the workers in very small amounts (1 to 2 gm.) in small containers as required, made it seem, at first glance, as if the possibility of dissemination of the material was very slight. Yet the clothes and the persons of many of the workers were said to be luminous in the dark following exposure to light.

By means of this "flash" test and examination in the dark-room, we were able to show that the air of the workroom must contain zinc sulphide. Dust samples collected in the workroom from various locations (tables, chandeliers, wall beams, etc.) and from chairs not used by the workers were all luminous in the dark-room. The hair, faces, hands, arms, necks, the dresses, the underclothes, even the corsets, of the dial painters were luminous. One of the girls showed luminous spots on her legs and thighs. The back of another was luminous almost to her waist. Dust from the machine shop below the painting room was luminous, and the same property was exhibited by office girls and by others about the plant not employed in the paint room. This, we think, is evidence that the powdered base was being carried in suspension about the paint room and even beyond its confines. Some quantitative notion of the rate of deposition is gained from the fact that dresses worn in the painting room for only a few hours exhibited luminosity in the dark following exposure to light. Dust samples collected from various places

recently oiled were luminous and showed traces of radium when examined later in Boston. These traces of radium, while necessarily minute, were definitely present.

The fact that the luminosity which developed after exposure to light faded away in the dark was merely an expression of the fact that the temporary response of the sulphide to light was far greater than the permanent luminosity produced in the sulphide by the radium. In our opinion, the luminosity, for example, in the skins of the workers, was due to paint which was present in such small quantities as not to be seen unless flashed. There can be no comparison between the amount of luminous paint persisting in the skin after vigorous washing and the rather thick streak of the paint on the dial of a watch. The transiency of the luminosity was not a proof that the skins did not contain radium, but merely that they did not contain enough radium to confer spontaneous visible luminosity. The same reasoning is applicable to the dust samples, which were not spontaneously luminous.

TABLE 1.—SUMMARY OF BLOOD FINDINGS IN TWENTY-TWO RADIUM WORKERS AS CONTRASTED WITH THE BLOOD FINDINGS IN NORMAL PERSONS

BLOOD FINDINGS			RADIUM WORKERS	NORMAL PERSONS
			%	%
Red blood cells	below 4 million		6	0
	between 4–6 million		75	100
	above 6 million		19	0
White blood cells below 7 thousand			27	0
Blood films	Polymorphonuclear cells	between 60–72%	55	100
		below 60%	45	0
		below 55%	32	0
	Lymphocytes	between 20–25%	18	100
		above 25%	64	0
		above 35%	27	0
	Mononuclear cells	between 3–8%	41	100
		above 8%	59	0
	Abnormal red cell forms		36	0
No blood abnormalities			0	100

By means of dental films, we endeavored to determine roughly the amount of gamma-radiation in the plant. Pfahler (7) has established the fact that any fogging of a sealed dental film within two weeks is evidence of an overexposure to radium or to X-rays. Films placed in various spots in the

plant—storeroom, telephone operator's room, office, etc.—all showed slight but definite fogging within one to two weeks. Films in the painting room showed distinct fogging at the end of two and three days, those at the weighing room end being the darkest.

In an attempt to determine whether or not radium had shown any effects on the personnel, we investigated the general health of the employees and their personal hygiene in the plant; we also examined the teeth and the blood of a representative group of workers. In all, twenty-two individuals from various parts of the plant were examined, fourteen of whom we considered to have had a long or an extensive exposure to radium or to the luminous paint, and eight of whom we considered to have had a slight exposure. Thirteen of these individuals were employed in painting or were working in the room with the painters. Nearly all of the workers reported themselves to be in good health. The general conditions of work were good and did not seem to produce fatigue, eyestrain, or other cause of complaint except a persistent luminosity of the persons of the workers.

Table 1 gives a summary of our findings in the bloods of the twenty-two persons examined, as compared with normal findings. The significance of these findings is that no blood was entirely normal, and that the findings characteristic of exposure to radium or to X-rays in excessive amount (3) (4) (5) (6) appeared in many of the blood films examined. The chief features observed were a reduction in the white cell count, a decrease in the percentage of polymorphonuclear cells, and an increase in the percentage of lymphocytes. These same findings were noted in some instances in previous reports by the Life Extension Institute on the health of these workers, but the Institute did not appear to have been aware of their meaning. If we consider only the fourteen cases with the greater exposure, instead of the mixed group of twenty-two, the percentage of blood abnormalities among the employees is markedly increased.

Conclusions

As a result of the observations and examinations already outlined, we are led to the following conclusions in regard to the necroses of the jaw under investigation. In the absence of any demonstration of the toxic properties of brushes, solvents, or zinc sulphide, the well-recognized biologic activity of radium causes us inevitably to regard it with suspicion. We have not been able to find accounts of necrotic processes in the bones of persons similarly employed elsewhere. We have, however, undoubted proof of excessive exposure to radiation in these workers, as evidenced by the abnormal condition of their bloods and by the fogged dental films. There is, in addition, evidence of an air-borne route by which radium itself may be absorbed. How it is exactly that these two processes—external radiation or a slow, long-continued absorption of minute quantities of radium—alone or in combination, have produced the bone destruction, we are unable at present to demonstrate. In view, however, of the descriptions of the effects of radium on bone already in the literature, in view of the overexposure to radiation which we demon-

strated in the plant studied, and finally, in view of the possibility of an actual absorption of radium through inhalation, we believe that radium has in some way caused these necroses of the jaw, as an effect hitherto not observed under these conditions of exposure.

Recommendations for Protection of Workers

This brings us to the question of recommendations for the relief of the conditions in the plant under observation, and for the future protection of similar workers. The recommendations are directed at the two sources of danger: the clearly demonstrated overexposure to gamma-radiation, and the less obvious, but probably more serious, possibility of the absorption of emanation or of radium itself.

Protection from gamma-radiation in such occupations must be improved. This necessity in the plant studied is clearly demonstrated by the fogging of all films to a greater or less degree in less than two weeks, no matter where the films were placed in the plant. The method employed will vary with the particular conditions of exposure, but will depend essentially on a proper screening of employees from the effects of concentrated sources of radiation (6) and on the prevention of the gradual deposition of radium-bearing dusts in their vicinity.

The absorption of the radium element itself must proceed in the group studied from the absorption of the luminous powder. There are three possible routes of absorption: the skin, the digestive tract, and the lungs. We do not believe that the skin is a favorable channel for absorption, in a situation of this sort, but it is certain that there was luminous powder in the skins of the workers which could not be removed by ordinary means.

The discontinuance, six months previous to the investigation, of the practice of pointing brushes in the mouth stopped what must have been a means of introducing relatively considerable amounts of luminous powder into the digestive tract. At the time of our study, paint smeared on the fingers of the operators during the process of pointing the brushes might possibly have been absorbed through the skin, or, after careless washing have reached the workers' mouths with their food. If the radium in the luminous paint is present as an insoluble salt, the digestive tract in an exposed worker is probably not a very great source of absorption; but it is, nevertheless, a possible route which, in the absence of definite knowledge, we cannot afford to neglect.

The inhalation of insoluble particulate matter into the lungs is an efficient means of securing its absorption (19) (20). The inhaled particles are held in the lung as in a reservoir from which they may gradually be dissolved and carried about the body. Our studies on the luminosity of objects and of workers in the plant proved the presence of dust, though it was not visible, in the air—dust presumably containing radium—which could certainly be breathed into the lungs. To this source of absorption, all those in the painting room were obviously exposed.

Similarly, persons engaged in the handling of larger quantities of luminous powder were exposed to absorption of radium by this route. The

man who weighed and issued the powder to the painters told us that the substance was extremely light, that it blew about if he breathed on it, and that to prevent losses it needed to be dampened slightly. This man had been employed about two weeks when we examined his blood, but, in spite of what would seem almost certainly a short exposure, we found suspicious alterations in the number and proportion of types of his white blood cells. The girl previously employed at this work is said to have noticed luminosity of nasal discharges in her handkerchief after blowing her nose.

Statements as to the facility with which the powder may be dispersed have been confirmed by us in experimental studies on the rate of settling after suspension in a chamber by means of an air blast. Once suspended, the material settled out very gradually and there was a demonstrable quantity still in the air at the end of forty-five minutes. We have also measured by means of the microscope the size of the particles in the powder. Eighty-three per cent. of the component particles are less than 4 microns in diameter, the majority of these being under 2 microns. Particles of this size will remain suspended for hours even in perfectly still air (21). According to observations made at this laboratory, the average size of particles of a similar mineral dust which had floated for two hours in still air was 3 to 4 microns, and many of them were as large as 6 or 7 microns.

Accordingly, in order that these modes of exposure to radium, or its emanation, should be avoided, in the handling of this powder or other similar preparations, we recommend the following: The mixing of radium with zinc sulphide and the manipulations necessary in the further handling of the radium-containing material should be carried out under a hood by a gloved operator in a room entirely separate from any workrooms. The material in a dry state should be mixed with the vehicle of the paint under a hood and in a separate room before being given out in small quantity to the painters. The painters should always work at desks covered with large sheets of paper to catch any dropped paint, and the papers should be burned and replaced with fresh ones each day. The workers should wear high-necked, long-sleeved work aprons which should be washed weekly. The ideal method of protecting the hands of the painters from possible skin absorption and of reducing the high degree of skin luminosity, so objectionable to the women, would be to require the wearing of thin rubber gloves. In surgical practice the wearing of such gloves is not found to be an impediment to the performance of delicate or long-continued operations, after the slight time required for becoming accustomed to their use. We, therefore, suggest that gloves be provided and that all workers be strongly urged to wear them. Workers unwilling to wear gloves should be required to wash their hands promptly after discontinuing work at lunch time and at 5 o'clock. The washroom should be provided with good stiff nail brushes and with an abrasive soap—a brush and a cake for each basin—and with individual paper towels. Furthermore, the workroom should be thoroughly scrubbed—walls, ceiling, desks,

floors, etc.—at least every two months. The weighing room should be made entirely separate and should be equipped with a proper hood in order to abolish the dust hazard. The possible danger from emanation is diminished, but not entirely removed even by these precautions so long as any radium is not hermetically sealed.

To be certain that such precautions are really efficacious, because of the serious nature of the disease process involved, we urgently recommend provision for competent and systematic medical supervision of the situation. Regular examinations of all workers, including examinations of the blood, and the routine carrying of a dental film at intervals ought to be instituted as procedures designed to determine whether or not employees are unduly exposed to radium. It is certainly advisable to employ enforced vacations in the cases of persons showing significant blood changes (22) (23). It is also an essential precautionary measure to have systematic examination and care of the teeth of all workers.

At the time of our investigation, a considerable number of the employees required dental attention. In the case of certain workers, extraction of teeth which needed to be removed had been refused for fear of initiating a necrosis of the jaw. This introduces a most difficult question and one that needs an answer. It is unfortunately not an easy problem nor one which removal from work for a considerable period will solve; for we know that more than three years after discontinuing work with luminous paint, Miss C. developed a severe necrosis following the extraction of a tooth. There is, to our knowledge, no way of determining for certain which individuals may or may not have a similar experience. Our opinion is that the best way out of the difficulty lies in getting the teeth of these workers in the best shape possible, without extractions in the case of persons long exposed. After this, it is within the province only of a competent dental surgeon, who knows thoroughly the facts in each case, to decide on the removal of teeth which require this procedure. We can only suggest, in general, conservatism in the matter, and in the contemplation of the removal of a tooth the clear understanding of the possible risks by both dentist and worker.

Summary

As a result of a careful examination, a novel condition affecting five workers with radium paint is described. The amounts of radium in this paint are extremely minute, so slight as to cause no one in this plant or in other plants employed in similar work to consider the possibility of a radium hazard. Blood examinations coupled with the use of photographic films have, however, demonstrated an overexposure to radium, and this overexposure is of peculiar type since it also permits the inhalation of particulate material containing a radium salt. The literature on radium indicates that under such circumstances radium is deposited in bone, and our own injection experiments verify this. Furthermore, clinical literature presents cases of jaw necrosis (one following tooth extraction) in patients who have received heavy treatment with radium

for mouth cancers. It seems necessary, therefore, to consider that the cases described have been due to radium. This is not finally proved, but since the remedial measures proposed are of general as well as specific import, it is felt that the safest course at the present time is to treat the situation in this light. It seems advisable to present an account of the situation without awaiting absolutely definite conclusions.

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BOOK REVIEWS

HYGIENE AND PUBLIC HEALTH. By *George M. Price*, M.D., Author of "A Handbook on Sanitation," "Tenement-House Inspection," "Hygiene and Sanitation for Nurses," "The Modern Factory," Director, Joint Board of Sanitary Control, Director, Union Health Center, New York City. Third edition, thoroughly revised. Cloth. Pp. 306 with index. Philadelphia and New York: Lea & Febiger, 1924.

The author of this book attempts to present in very condensed form an epitomized survey of hygiene and public health. Since the entire volume, including index, comprises but 306 pages, no topic is treated with any but the extremest brevity.

The chapter headings are: Housing Hygiene, Child Hygiene, School Hygiene, Industrial Hygiene, Public Water Supply, Foods, Meat Foods, Milk Supply, Disposal of Waste Matter, Public Nuisances, The Prevention of Infectious Diseases, and Federal Hygiene.

At the conclusion of each chapter is a list of questions to which answers are found by referring to the heavy type of the paragraphs in the text preceding.

While the book is technical in scope, it is popular and elementary in style, with no references but with a good index. The elementary student of public health may find it a useful reference text or dictionary of public health and hygiene.—*Philip Drinker.*

THE MEDICAL ASPECTS OF CHEMICAL WARFARE. By *Edward B. Vedder*, Lieut. Colonel, M.C., U. S. A. With a chapter on the Naval Medical Aspects of Chemical Warfare. By *Duncan C. Walton*, Lieut. Commander, M.C., U. S. N. Cloth. Pp. xvi, 327 with illustrations, appendix, and index. Baltimore: The Williams & Wilkins Company, 1925.

"There has been and there still is considerable prejudice against the use of gas in warfare." This prejudice, according to the author, apparently proceeds from three sources: first, because the use of gas was started by the Germans in violation of their existing treaty obligations; second, because it is a new weapon and shares the criticism usually leveled at new weapons; and third, because it is "barbarous and inhumane."

To the first two criticisms, the author takes no exception, but on the third, by statistics from the British and American armies, he shows at some length that death and permanent disability from gas were far less than from gunshot and explosives. "Gas causes a smaller proportion of deaths than other weapons. Only 1.73 per

cent of our [American] total gas admissions [to hospitals] resulted in death. Yet 8.26 per cent of our gunshot admissions resulted in death." Furthermore, total disability from gassing is shown to be lower than from other military agents, while statistics indicate that the inhalation of chlorine, even in dangerous doses, reduces the probability of subsequent pulmonary infection, such as tuberculosis.

The outline history of gas warfare is given admirably, in condensed form, and is followed by chapters on the physics and elementary chemistry of chemical warfare, and on smoke and gas clouds. The chapter on chemical warfare materials and the chronological introduction of these materials into the late war is of special interest. The author's physiologic classification of war gases comprises: (1) pulmonary irritants, (2) vesicants, (3) lacrimators, (4) irritant gases, (5) direct poisons of the nervous system, and (6) gases which act by interfering with the respiratory properties of the blood. Then follow five chapters in which the physiology and pathology of the various warfare gases are discussed in detail.

Another chapter is devoted to gas masks, their historical development and a comparison of the various types of masks, with brief discussions of their peace-time application. Protective measures against gas are discussed from the standpoint of the military doctor, but ample details as to the use of protective clothing, the meteorology of gas attacks, the effect of the terrain, gas-proof shelters, etc., are given to make these chapters all of peace-time interest.

The concluding chapters on the ultimate results of gas poisoning and the treatment of respiratory diseases by chlorine are both of decided peace-time interest. In summarizing experiments on the recovery of dogs from gassing, the author states:

> 1. That there is no point up to nine months at which it can be said that the majority of the dogs show no pathological lesions. Recovery from lethal concentrations of mustard [gas] is evidently a longer process than recovery from lethal concentrations of phosgene.
>
> 2. However, even after such lethal concentrations of mustard, in 13 out of 32 dogs, or 40 per cent, no lesions could be detected as the result of gassing.
>
> 3. Bearing in mind the fact that very few men have ever been gassed with such lethal concentrations in the field, it seems reasonable to conclude that only a very small percentage of men will present any pathological findings more than eighteen months after gassing by mustard.

Referring to men gassed in the war, he says:

> . . . . In the vast majority of human cases who are not gassed so severely, and who receive infinitely better care in hospital, all lesions must have disappeared a year after gassing, and such minor lesions as may remain in a minority of cases, can hardly be a cause of serious disability. By far the greater proportion of cases that suffer disability more than a year after gassing, are suffering from neurasthenic conditions, particularly functional disordered heart action, or a neurasthenic condition of the respiratory center. Treatment of such cases should be directed along these lines.

The chapter on The Naval Medical Aspects of Chemical Warfare covers more briefly much the same ground. The application of gases to the fumigation of ships, the physiology and pathology of some of the war gases, fumigating gases, and toxic gases—

such as ammonia, hydrogen cyanide, nitrous fumes, and hydrogen sulphide—are discussed in some detail.

For those interested in general questions of the toxicity of gases used in warfare, or the less dangerous gases encountered in industry, this book is well worth possessing. It will be a useful addition to any library on general public health, inasmuch as gases, their toxicity, and protective devices against their inhalation are today important public health subjects.—*Philip Drinker.*